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Spatial variability of the response to climate change in regional groundwater systems – Examples from simulations in the Deschutes Basin, Oregon

M.S. Waibel [a], M.W. Gannett [b,*], H. Chang [c], C.L. Hulbe [a,d]

[a] Department of Geology, Portland State University, P.O. Box 751, Portland, OR 97201, United States
[b] U.S. Geological Survey, Oregon Water Science Center, 2130 S.W. Fifth Ave., Portland, OR 97201, United States
[c] Department of Geography, Portland State University, P.O. Box 751, Portland, OR 97201, United States
[d] University of Otago School of Surveying, Dunedin, New Zealand

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SUMMARY

We examine the spatial variability of the response of aquifer systems to climate change in and adjacent to the Cascade Range volcanic arc in the Deschutes Basin, Oregon using downscaled global climate model projections to drive surface hydrologic process and groundwater flow models. Projected warming over the 21st century is anticipated to shift the phase of precipitation toward more rain and less snow in mountainous areas in the Pacific Northwest, resulting in smaller winter snowpack and in a shift in the timing of runoff to earlier in the year. This will be accompanied by spatially variable changes in the timing of groundwater recharge. Analysis of historic climate and hydrologic data and modeling studies show that groundwater plays a key role in determining the response of stream systems to climate change. The spatial variability in the response of groundwater systems to climate change, particularly with regard to flow-system scale, however, has generally not been addressed in the literature. Here we simulate the hydrologic response to projected future climate to show that the response of groundwater systems can vary depending on the location and spatial scale of the flow systems and their aquifer characteristics. Mean annual recharge averaged over the basin does not change significantly between the 1980s and 2080s climate periods given the ensemble of global climate models and emission scenarios evaluated. There are, however, changes in the seasonality of groundwater recharge within the basin. Simulation results show that short-flow-path groundwater systems, such as those providing baseflow to many headwater streams, will likely have substantial changes in the timing of discharge in response changes in seasonality of recharge. Regional-scale aquifer systems with flow paths on the order of many tens of kilometers, in contrast, are much less affected by changes in seasonality of recharge. Flow systems at all spatial scales, however, are likely to reflect interannual changes in total recharge. These results provide insights into the possible impacts of climate change to other regional aquifer systems, and the streams they support, where discharge points represent a range of flow system scales.

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1. Introduction

Understanding the potential impacts of climate change on groundwater systems is currently among the central problems in hydrological sciences (Bovolo et al., 2009; Döll, 2009; Green et al., 2011; Loáiciga, 2009; Taylor et al., 2010). Groundwater systems and the streams, ecosystems, and human systems they support will respond in complex ways to future changes in energy and moisture balances. However, understanding and quantifying the response of groundwater systems to climate change is confounded due to their variability, our imperfect knowledge of the subsurface, and the scarcity of detailed studies from which we can gain general insights. Hydrologic models of well characterized aquifer systems provide opportunities to better understand climate change impacts on groundwater (for example Eckhardt and Ulbrich, 2003; Maxwell and Kollet, 2008; Scibeck and Allen, 2006; Scibeck et al., 2007; Vaccaro, 1992), but such models exist for only a small fraction of aquifer systems.

One of the principal ways in which groundwater systems are expected to be affected by climate change in the Pacific Northwest is a change in the timing of recharge (Chang et al., 2010). The timing of recharge can have a major influence on the seasonality of fluctuations in hydraulic head and groundwater discharge to streams (baseflow) (Manga, 1997, 1999; Gannett et al., 2001). As a general rule, the response of aquifer systems to transient signals, such as seasonal recharge pulses, is scale dependent (Manga (1996, 1999)). In the upper Deschutes Basin (Fig. 1), shallow, local-scale flow systems typically exhibit larger seasonal

* Corresponding author. Tel.: +1 503 251 3233; fax: +1 503 251 3470.
E-mail addresses: waibelms@pdx.edu (M.S. Waibel), mgannett@usgs.gov (M.W. Gannett), changh@pdx.edu (H. Chang), christina.hulbe@otago.ac.nz (C.L. Hulbe).

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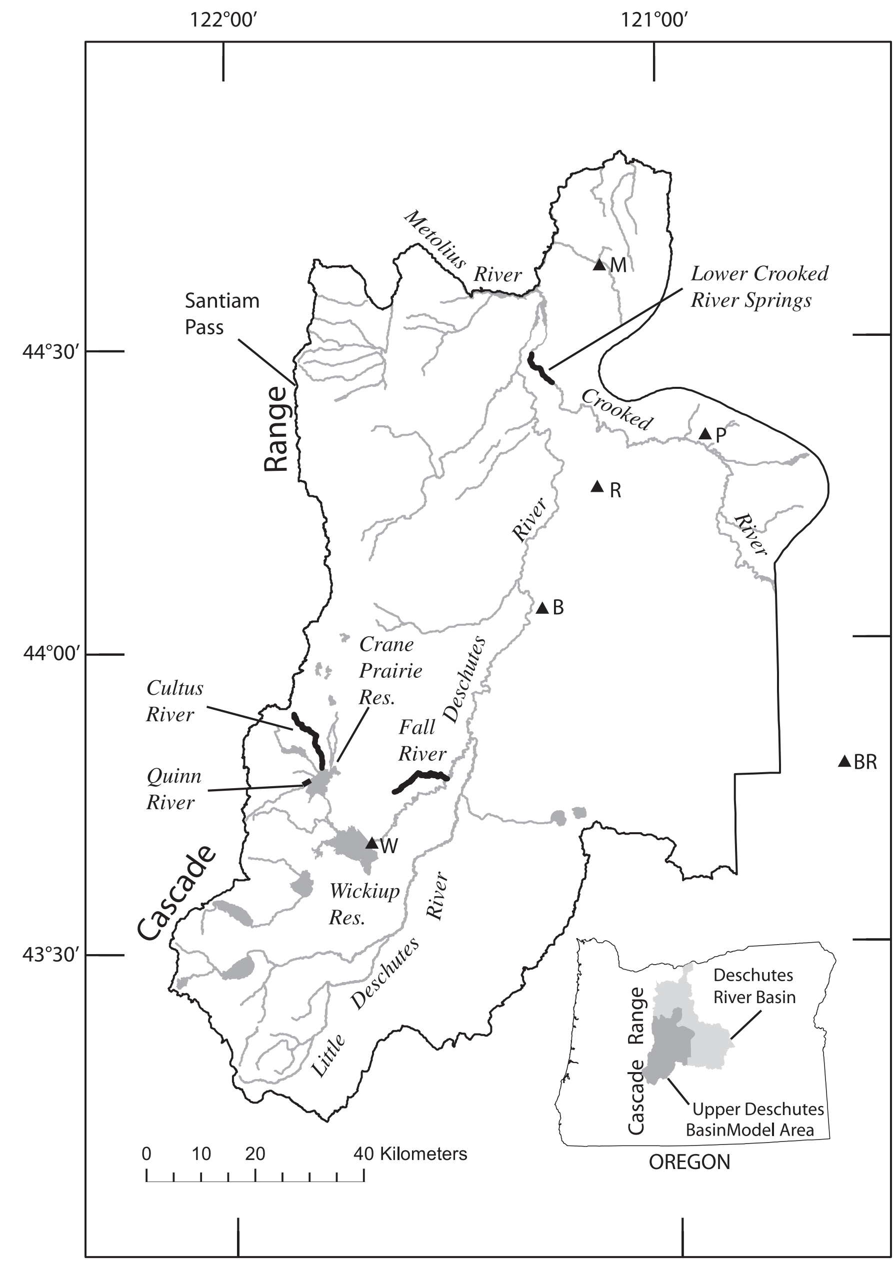

Fig. 1. Location of the Cascade Range and upper Deschutes Basin in Oregon and major geographic features. Stream reaches considered in the discussion are shown as bold lines. Triangles correspond to weather stations in Table 1: M, Madras; P, Prineville 4 NW; R, Redmond – Roberts Field FAA; B, Bend; BR, Brothers; W, Wickiup Dam.

variations in head and discharge compared to deeper, regional-scale systems with longer flow paths along which seasonal signals are diffused. A number of studies in other basins (for example Maxwell and Kollet, 2008; Scibeck et al., 2007) show that factors such as aquifer heterogeneity, proximity to stream boundaries, and depth to water can result in spatial variability in the response to climate change within aquifer systems. The spatial variability of climate change impacts to regional groundwater systems as a function of scale, however, is not commonly described in literature.

In this paper we use surface process and groundwater flow models to explore the scale-dependent spatial variability of the response to climate change within the regional aquifer system in the upper Deschutes Basin of central Oregon (Fig. 1). Our goal is to provide some general insights that will be broadly applicable to other regional aquifer systems.

Ecosystems and human systems dependent on groundwater and groundwater-fed streamflow exist throughout watersheds. As the response of aquifer systems to climate change varies spatially, the degree of vulnerability of ecosystem or human uses varies as well. Understanding the spatial variability of the response of groundwater systems (and hydrologic systems in general) to climate change may be important for identifying vulnerabilities and planning adaptation strategies.

1.1. Background

Global climate models (GCMs) predict increases in mean-annual temperature on the order of 3 °C by the 2080s in the Pacific Northwest of the United States compared to recent conditions as represented by the period from 1970 to 1999 (Mote and Salathé, 2010). Projected changes in precipitation are more variable with